THE

Artesian Wells of Denver

A REPORT

BY A

SPECIAL COMMITTEE

OF THE

COLORADO SCIENTIFIC SOCIETY.

PUBLISHED BY THE SOCIETY.

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DENVER:
NEWS PRINTING COMPANY,
1884.

Letter of Transmittal.

To the President of the Colorado Scientific Society:

DEAR SIR:—

The committee appointed by you in February last to investigate the artesian wells of Denver and vicinity, having completed their examination, respectfully submit the following report. Its completion was somewhat delayed through the inability of some of the members of the committee to do the work assigned to them. Another delay arose from the fact that it was understood that the Denver Chamber of Commerce would undertake the publication of the report for free distribution, but although the completed report was handed in to the Chamber in June, it was not until July 21st that the report was returned with the statement that the Chamber of Commerce was unable to expend the amount necessary for its publication, consequently the burden of printing the report has fallen upon the Society, and it has been decided to issue it immediately and in advance of the regular publication of the Transactions of the Society, which will be begun in October next.

Respectfully,

WHITMAN CROSS,
FREDERIC F. CHISOLM,
REGIS CHAUVENET,
P. H. VAN DIEST,
Committee.

Introduction.

The discovery of artesian well water in Denver, in the spring of 1883, was undoubtedly, for the city and its immediate vicinity, the most important event of that year, particularly as the numerous subsequent borings have demonstrated the presence of several available subterranean water courses. The interest awakened by this discovery, especially along the eastern base of the mountains, is most natural, and the determination of the nature and extent of the water supply which has been found, becomes of importance to many.

For this reason the subject was considered worthy of investigation by a special committee of the society, with the object of giving to the public such information upon artesian wells in general and those of Denver in particular, as should make plain the conditions here prevailing, and at the same time enable persons in other localities to judge whether the water courses underlying Denver may be tapped at those points, or not.

In carrying out this investigation it was judged best to make such a division of labor that each member of the committee should treat the subject from his own individual standpoint, pursuing a special line of investigation in order thereby to economize time and make the results available at the earliest practicable moment.

The following report consists, therefore, of four separate sections, or reports, as follows:

Section I., by Whitman Cross, defining an artesian well and giving data concerning the geological relations of the Denver basin, its extent, etc.

Section II., by Frederic F. Chisolm, giving the history of artesian well boring in Denver, observations of individual wells with some conclusions and recommendations. Also a brief description of the machinery used in boring.

Section III., by Regis Chauvenet, giving the analyses of the water from different depths.

Section IV., by P. H. van Diest, general information in regard to the accumulation of subterranean water bodies, here and elsewhere, rainfall, etc.

SECTION I.—BY WHITMAN CROSS.

Geological Relations.

DEFINITION OF AN ARTESIAN WELL.

An artesian well may be defined as one which taps a subterranean water course or body of water, at a point where it is under hydrostatic pressure, the latter forcing the water to rise in the new channel.

That all artesian wells should conform throughout to the first ones, in Artois, in France, from which the name was derived, is by no means necessary. The essential conditions may be briefly stated as follows: There must be an inclined subterranean water course with impervious material above and below it, and the inclination must be more or less interrupted at some point, so that when a new channel is formed (as by boring,) at some lower level than that of the source, the water will escape through it more easily than by any other outlet. From this general statement it is evident that the geological age of the water bearing rock is of no moment. Given the conditions above mentioned and there is no reason why water should be obtained in Cretaceous strata, as at Artois, with greater certainty than in Silurian or recent formations. It is not even necessary that the water course should be in stratified rocks, although it is plain that the instances in which the above conditions can be fulfilled in any other than sedimentary rocks, must be extremely rare.

It is commonly found that the area within which artesian wells have been secured lies in a simple synclinal fold or a basin of sedimentary rocks, and that the water bearing layers outcrop at some distance, and, necessarily, at a higher level

than the site of the wells. By a study of the geological structure of the surrounding country, it may therefore be quite accurately determined how large the area is within which artesian wells may be obtained, and, in some cases, the depth at which a given stratum may be struck.

GEOLOGY OF THE COUNTRY ADJACENT TO DENVER.

That Denver and the plains about it are underlaid by sedimentary rocks of Silurian, Carboniferous, Triassic, Jurassic and Cretaceous ages, has been clearly established by the United States Geological Survey, under F. V. Hayden, and is well known to all. The two lower members of the series are not exposed within the area of the present investigation, because the deposits of later ages have nowhere been eroded to a sufficient extent. At Perry's park, Manitou, and Cañon City, however, the lower strata are plainly seen.

Owing to a sharp folding of these sedimentary strata at or near the contact with the Archaean granites, gneisses and schists of the foot-hills, which extends nearly the whole length of Front or Colorado range of the Rocky Mountains, each stream issuing from the mountains has exposed a more or less perfect section of the series from the Trias to the coal formation. The familiar sections at Morrison, Golden and Boulder are examples.

The Hayden map of this region shows the strata of the Laramie or Lignitic group to immediately underlie the surface at and about Denver. (This group, whose geological position is not definitely settled, will, in this discussion, be considered as the uppermost member of the cretaceous series.) Unless, therefore, the wells of Denver have penetrated the Laramie and have passed into strata of a lower horizon, it is plain that the question before us may be limited to a study of that formation, its character and extent. At least no strata of *older* groups are concerned in the matter.

The geologists of the Hayden survey did not recognize any formation of later date than the Laramie as present in the

district immediately adjacent to Denver, but the researches of the present United States Geological Survey have shown that the Laramie is overlaid by a very well characterized formation, which may be easily recognized wherever it occurs, by the materials of which it is made. The difference is simply this, that while the sandstones and conglomerates of the Laramie are made up of minerals and rock fragments derived from the granites and gneisses of the main range to the west, the later formation is composed, in a large degree, of pebbles and fragments of an eruptive rock of the *andesite* group, one of the most pronounced Tertiary rocks. This difference, which is plain at a glance in the coarser-grained beds, may be easily detected, by microscopic study, in the finest sand layers.

The Tertiary andesitic pebble beds are well shown in Table Mountain, at Golden, and their relation to the coal-bearing formation (the Laramie) is clearly seen in Green Mountain, near Morrison. From these points the formation extends eastward as far as the Platte at Denver. Leaving the description and all further data as to extent of this formation to a forthcoming report on the geology of the Denver basin, by the United States Geological Survey, we will proceed to show why this recently recognized formation is of value to the present study.

In the ravine by St. Luke's Hospital in North Denver, where the first artesian water was struck in the McCormick boring, the lower strata of this Tertiary group are exposed as dark and light sandy beds, containing leaves and stems of plants, as in Table Mountain. Microscopical examination shows the abundant presence of augite, hornblende and other minerals derived from the andesite, of which small pebbles are also found occasionally. At 240 feet in the McCormick boring no such material can be detected. From the examination of material from the Windsor, Metropolitan and other wells, it is determined that the lowest layers of the Tertiary andesitic beds are but thirty to fifty feet below the level of Larimer street in East Denver.

The artesian wells of Denver start, then, at or a little above the uppermost layers of the Laramie, and as these lie prac-

tically horizontal, the borings have very nearly the entire thickness of that formation to pierce before reaching the main coal beds. This thickness is, as shown in the next section, from 1,200 to 1,500 feet.

Having shown that the water-bearing layers lie in the Laramie, it will be well to give concisely the characteristics of that group.

THE LARAMIE FORMATION.

The Laramie, or, as it was designated by the Hayden survey, the "Lignitic" formation, is one of the most variable known, *i. e.*, in the character of a given stratum at different points, or in the sequence of strata as exposed in different places. For this reason no attempt will be made to give a detailed section, but rather the variability will be emphasized. At the base of the group lies a persistent sandstone series, near the bottom of which the workable coal layers are situated. This series has a thickness of from three hundred to six hundred feet, or even more in some places, and is composed of a fine even grained rock at the base, while near the top fine conglomerates and heavily iron stained layers appear. Above this sandstone series (which embraces thin, unimportant clay layers), comes a series of alternating clay and sand strata with all possible intermediate stages betwen a typical sandstone and a clay bed. These layers are seldom of the same composition and consistency for any great distance laterally, but are especially subject to variations in thickness. Thus, a complete section at one point would show a prominent sandstone series, including coal strata, perhaps 350 feet thick with clay, sandstone and intermediate strata above, in a total thickness of about 900 feet. In a section a few miles distant the bottom sandstones might be 600 feet thick, and the mixed series, though of the same total thickness, might consist of clays and sandstones, but in different relation from that observed in the first case.

With such a formation, it is evident that no calculations as to the thickness to be passed through by the borings at any

given place can be very accurate, although the very variability mentioned serves to make general statements comparatively safe. The thickness near Golden may be roughly estimated as from 12 to 1,500 feet, and the same may be adopted here.

The statements in regard to the Denver wells are fully in accord with what has been said. The strata encountered in the various wells can never be accurately compared, partly as a consequence of the usual method of boring, but more frequently the observed differences are to be attributed to the changeability of the strata themselves. The deepest well yet sunk, that at the Court House, strikes iron bearing water at a depth of over 900 feet, and this is very likely from one of the iron stained layers near the top of the sandstone series which forms the base of the whole group.

Throughout the whole series small layers of carbonaceous matter are found and these produce the substance called coal, which has been announced from several wells, *e. g.*, Court House.

The variations of composition and texture account for all the peculiarities noticed in the wells. The numerous sandy layers at one place are accompanied by numerous flows of water, and the more porous condition of a layer in one well accounts for the increased pressure and amount of flow over that found for the same layer in another well.

FORM AND EXTENT OF THE DENVER BASIN.

From the foregoing it is clear that the area within which the water courses met with in the Denver wells may be found, is practically identical with the coal basin, for the workable veins are very near the base of the Laramie formation. The western border of the basin is well defined, running from near Platteville, on the Denver Pacific, along the south banks of St. Vrains and Boulder creeks, passing through Erie, Canfield and Marshall, and from the latter place south, crossing the various streams issuing from the mountains, and being mined at Ralston Creek, Golden and Morrison. The Platte is crossed

again at Archer's and the line continues on southeast, passing near Sedalia. East of the Platte the plain is underlaid by the Laramie for an unknown distance, but the artesian basin is partially defined by the presence of coal at Franktown, on the D. & N. O. R. R., and by several outcrops on Coal and Box Elder creeks, east of Denver.

Along the line of this basin from Marshall south to the neighborhood of Sedalia, the whole thickness is exposed and the lower part at least is upturned at a very steep angle, being indeed vertical for a large part of the distance.

The natural streams and ditches leading from them, thus pass over the edges of the porous sandstones at an elevation of from two hundred to six hundred feet above Denver, and the pressure shown in the Denver wells is plainly accounted for. On the east, the outcrops on Box Elder creek are also some four hundred feet above Denver, and although it is by no means determinable how much of the water supply comes from the east, it is very possibly a considerable amount.

The shape of the artesian basin is thus an elongated oval, whose axis corresponds nearly to the valley of the Platte. The length along this axis from Platteville to Sedalia is about fifty-six miles, and the breadth, measuring from Golden through Denver to Box Elder creek, is thirty-two miles. The rim at Golden and Box Elder is nearly four hundred feet above Denver. Whether the fold shown by the cross section of the basin is deepest under Denver cannot be well determined, but it is probable that the Platte follows approximately the trough of this northeast and southwest fold.

If the outline of the basin above indicated is correct, Denver and localities in the Platte valley are best situated to secure artesian water under considerable pressure, for they lie above what is probably the lowest part of the fold which produces the pressure. As the outcrops of the Laramie strata are approached, the chances of obtaining a well with pressure enough to cause simply an overflow diminish rapidly.

The borings at Greeley, Colorado Springs, Pueblo, and on the great plains are in strata below the Laramie; and hence,

whatever water they may find, comes from layers different from those supplying the Denver wells.

In general it may be stated in regard to outside localities, that if the Laramie formation is present, with upturned edges along the base of the mountains, the chances for an artesian well are good. If the lower members of the Cretaceous form the surface, it is probable that a water supply can seldom be procured, although it is in each case to be determined only when the geological structure of the region is plain.

In conclusion it may be well to point out that the bottom sandstone of the Laramie, which no well in Denver has yet reached, seems likely to contain a large supply of water. Whether the density of the sandstone is such as to interfere with the transmission of pressure is something to be determined by experience alone.

It is also probable that water obtained from lower horizons in the Cretaceous formation will be less pure than that which comes from the Laramie, not only because it will have passed through a greater extent of rock material, but because the lower beds abound in soluble salts, such as sulphates of soda and lime, and other bases, which are readily taken up by percolating waters. Already at Greeley a well sunk in the clays below the Laramie formations yielded an impure water, contaminated with oil.

SECTION II.—BY FREDERIC F. CHISOLM.

Data Concerning the Denver Wells.

The first attempt at sinking an artesian well in the neighborhood of Denver, was made in February, 1874, under the charge of Mr. Eli Brooks. This well was sunk to a depth of 795 feet by private parties, and was located at the Cemetery east of Denver. Three water bearing seams of sandrock were cut, the first at 255 feet, the second at 540 feet and the third at 780 feet. None of these seams showed pressure sufficient to bring the water to the surface, and the attempt was finally abandoned.

The subject was not again agitated until in March, 1883, when Mr. R. R. McCormick, who was boring for coal near St. Luke's Hospital, in North Denver, was forced to abandon the attempt on account of a large flow of water which rendered further progress with the tools in use impossible. This water was characterized by its extreme purity and its superiority over the water furnished by the Denver Water Company from the Platte, and the interest created by its discovery was very great. The question of its source was discussed at great length, and it is largely to the emphatic and, as later proved, correct assertion of Mr. Horace Beach, the United States Commissioner in charge of the government wells on the plains, that this water was artesian and not derived by seepage from artificial lakes near by, that confidence was established in these wells, and boring begun extensively. To the enterprise of Messrs. Phillip Zang, Thos. G. Anderson and H. A. W. Tabor, and to the owners of the Lion Brewery, who immediately sank wells, is largely due the establishment of the fact that Denver is underlaid by economically available streams of artesian water. Since that time a great number of wells have been sunk everywhere, cutting

these water bearing sands, and the number of wells, which is now about eighty, is being steadily increased. Everywhere in the immediate neighborhood of Denver, alternating seams of impervious clays and porous sandstones have been met with in the Laramie formation to the greatest depth yet attained. At the Court House, the well sunk by the County Commissioners reached a depth of 900 feet, finding at that point a good flow of water.

There is considerable difference noted in different wells both with regard to the number of sandstone strata cut and the pressure of the water in them. In some cases six or seven have been met above the depth of 375 feet, while in others only one has been cut. In some cases the seam generally encountered at from 235 to 275 feet, furnishes a fair supply of water which rises above the surface, but again the water from this same vein only reaches a point from ten to forty feet below the surface. Two main sandstone layers bearing water of sufficient hydrostatic pressure to ensure a regular supply without pumping have been identified, one at 375 feet and the other at 600 feet depth, at the corner of Lawrence and Sixteenth streets, and the flows from these two seams are for convenience sake named the 375 foot and 600 foot flows.

The pressure from these two different seams varies greatly at different points, this variation being unquestionably due to the character of the Laramie formation.

The difficulties met with in sinking these wells have not been very great, and are due mainly to continuous cavings-in from seams of shale and sandstone above, with the consequent clogging of the machinery and breaking of ropes, necessitating sometimes, as in the Court House well, a delay of months.

The work of sinking the majority of the wells in Denver has, however, been very simple and rapid, the progress made being frequently seven and eight feet per hour. These wells are comparatively inexpensive, costing for drilling about $2.00 per foot of depth.

It has been found impossible, with the time and means at the committee's disposal, to make any estimates as to the

average pressure and flow from the 375 foot and 600 foot seams. The extreme variation of the sandstones of the Laramie, within very small distances, both in their thickness and porosity renders all possible estimates unreliable, and both pressure and flow are likely to change without easily apparent cause. Roughly estimated, the pressure from the 375 foot seam seems to average at present about ten pounds per square inch, and from the 600 foot seam about twenty-eight pounds. No satisfactory records have been kept anywhere, and in a great number of cases the pressure and flow have never been even roughly ascertained.

There are now approximately eighty wells flowing in Denver, and putting the average outflow of each at twenty-five gallons per minute throughout night and day, the total product of the wells would be about 2,880,000 gallons per day of twenty-four hours.

If this estimate be compared with that made in January, 1884, it will be seen to be considerably less, but it should be recollected that the January estimate was made in the crudest and most careless way, each well being stated, on no authority, to produce from 100,000 to 200,000 gallons of water per twenty-four hours. Necessarily, however, any estimate whatever is incorrect, and will be so until laws governing the management of artesian wells are made and enforced. The subject is one of vital importance to the city, and action in the matter cannot be too strongly urged.

The considerable differences in the pressure from the same flow in wells in different localities is readily explained by the ever varying character of the strata of the Laramie formation. In one case at 210 feet a vein of sandrock was cut which was but seven feet thick, very compact, and did not furnish hydrostatic pressure sufficient to bring the water to the surface. Only five blocks away however, this same seam was found to be forty feet thick, of loose sands and the water from it flowed over the surface quite freely. The differences in the pressure and flow at different points in the same water-bearing seam are undoubtedly due to the variations in density and thickness.

Upon the subject of the so-called "magnetic" water, it is scarcely necessary to say that water cannot be magnetic. The magnetism observed is located in the casings, and is due to the magnetizing of the steel drill by friction and pounding, and this magnetism is communicated to the casing during the passage of the drill when lifted and lowered.

The position in the sandstones in which the greatest flow of water is encountered varies somewhat, being sometimes on the top, but far more commonly on the bottom of the bed, the rule being that the flow in any one seam increases as the bore advances toward the lower portion of the sand.

INDIVIDUAL WELLS.

The Zang well in north Denver was the first sunk after the strike of water in the McCormick well. In this well the work of sinking was very poorly done, and many inequalities were made in the bore. At first the well was not cased, and the pressure was sufficient to force the water to the top of the brewery, a distance of about fifty feet. Shortly after completion the flow began decreasing, and the owners then put down a four-inch casing, which was afterward removed, the well cleaned out and a six-inch pipe inserted, and seed-bag packing put down. Owing to poor drilling, however, this packing did not prevent waste through upper flows, and the pressure is now so low that only enough water is obtained to supply the boilers and a small neighborhood demand. Mr. Zang let a contract for a new well to be 600 feet, or more, in depth, and work was begun in sinking May 29th. The new well was completed to 560 feet depth June 13th, and furnishes an immense flow of water, estimated roughly at 400,000 gallons daily. The depth of the old well is 300 feet.

The well at the Lion brewery is 294 feet deep, of which 278 feet are cased, the diameter of the casing at the bottom being two and one-half inches. The pipe is packed with seed-bags. No diminution of pressure was observed, the head being about forty feet, until the wells in the Denver brewery

and the Milwaukee brewery were finished, when the pressure decreased considerably, but has remained unchanged for nine months. At present the flow is twenty gallons per minute, and the head about twenty feet. The decrease here was unquestionably due to the tapping of the same water-bearing seam of sandstone by other wells in the immediate vicinity.

The Anderson well, near the Colfax avenue bridge, was first sunk to a depth of 375 feet, in which distance water-bearing seams were cut at 154, 244, 290, 350 and 375 feet. The well was cased with three inch pipe to a depth of 300 feet. The pressure at first was twenty-five pounds, but this decreased to such an extent that the casing was taken up and the well sunk to a depth of 610 feet to cut the 600-foot flow. Since this flow was cut there has been no diminution whatever in the pressure. The original decrease was probably due to bad work in sinking, imperfect casing and a lack of packing. The well is one of the typical wells of the Denver basin, and the different strata passed through are given in full, as illustrating the principal features of the Laramie formation.

From the surface the bore passed first through

A seam of gravel and surface wash	12	feet.
Clay	17	"
Sandstone	1	foot.
Hard clay	94	feet.
Hard sandstone	8	"
Clay slate	22	"
Sandstone (first flow of water)	14	"
Hard clay	24	"
Sandstone	2	"
Very tough, hard clay	50	"
Sandstone (second flow of water.)	16	"
Hard clay	30	"
Sandstone (third flow of water.)	10	"
Blue clay	8	"
Sandstone (fourth flow of water.)	12	"
Soft clay	15	"
Dark hard clay	15	"
Loose, white sandstone (fifth and greatest flow of water,)	25	"
Total depth of old well	375	"

When the well was sunk further the drill passed through alternating seams of sandstones and clays of different hardness, and nothing noteworthy was observed. The section given here is substantially the same as that found elsewhere, and may be taken as typical.

The Tabor Opera House well is 390 feet deep, and is cased with four-inch pipe. Four flows were cut at 179, 220, 333 and 375 feet. There has been a great decrease in the pressure here, from thirty-six pounds at completion to about five pounds. Decrease here is due to the fact that only 190 feet are cased, the lower 200 feet of the well having caved very badly. Some pieces of rock of high specific gravity were pumped up after the flow decreased. The flow is now again increasing.

The County Hospital well is 633 feet deep, and cased for 621 feet with five and five-eighths-inch pipe. The first flow was cut at 445 feet and the second at 628 feet. The head is about fifty-five feet. No artificial packing was employed.

The well of the Anheuser-Busch Brewing Company is 314 feet deep, and cased the full distance with three-inch pipe. Several flows were cut, only the fifth being used. Three seed-bags are used as packing. No decrease noted. Head now forty feet.

The Windsor well at the Windsor hotel is 533 feet deep, and cased the whole distance. Two main flows were cut, one at 335 and the other at 515 feet. No packing was used. The head at completion was for the first flow twenty-five feet, and for the second sixty feet. There has been a great decrease of pressure here, and the water is now pumped. Roughly estimated, the head from the lower flow now is about twenty feet. It has recently been discovered that a deposit of white sand has settled in the bottom of the well, and the decrease is, in all probability, due solely to the resistance to the flow offered by this sand.

The Charles well, at the corner of Curtis and Fifteenth streets, was the first to reach the 600-foot flow. Its depth is 580 feet, and it is cased with four-inch pipe for 564 feet. The pressure was, when first struck, and until October, 1883, about

seventy pounds, but owing to other wells being sunk in the immediate neighborhood, the pressure has decreased until it is now about twenty pounds only. The principal flows encountered were met at a depth of 235, 364 and 564 feet.

The well at the Milwaukee brewery is 354 feet deep, and at first was cased only to bed-rock, but later a four-inch pipe was put down 284 feet, and two seed-bags inserted against hard rock for packing. The head is now about fifty feet, and no decrease of pressure has been observed. The well was completed in September, 1883, and none have been sunk since near by.

The well of the Denver Brewing Company is 358½ feet deep, and is cased 306 feet. Flows were cut at 150, 200, 306 and 358 feet depth. The pressure is said to be about twenty pounds, and there has been no decrease up to date. This well is packed with one seed-bag.

The Spitzer well, on Eleventh and Larimer streets, is 350 feet deep, and but slightly cased at the top. The flow was very strong at first, but has decreased more than one-half. It is said to run irregularly. The decrease here is probably due to the lack of casing.

The Denver Water Company has sunk three wells near the engine house at the works. They are situated in the angles of a triangle, the sides of which are approximately 250 feet each, and were so placed as to test the effect of wells near each other. In No. 1 the first water was struck at 260 feet, which yielded eight gallons per minute. Second flow was struck at 348 feet, third at 385 and last flow about 555 feet. The total depth of the well is 587 feet. The total flow at completion was ninety-five gallons per minute, and the total pressure twenty-six pounds. The second well was similar in every respect, and reduced the flow from No. 1 about one-third. Well No. 3 reduced the flow from the other two, so that the total flow from the three wells is but little more than that obtained from the first well alone.

Well No. 4, near the Rio Grande shops, is about 1,500 feet

away, and struck all the upper flows, but without affecting the others.

The Metropolitan well, at the corner of Sixteenth and Holladay streets, is 545 feet deep, and is cased 360 feet with eight-inch pipe, and 540 feet with three-inch pipe. The upper flow was cut at 365 feet and the lower at 545. No packing is used. The pressure here is very great, and, it is claimed, has increased. The two flows are kept separate, and the pressure of the upper is twelve pounds, and of the lower, said to be eighty-five pounds.

The Brown well, on Capitol avenue, is 708 feet deep, and cased with 8¾, 7⅞, 6⅝, 5⅝ and 4⅝-inch pipe. Three flows were encountered, the last two being separated. No packing is used. The pressure from the lowest flow is forty pounds.

The Eckhart well, at the corner of 15th and Stout streets, is 580 feet deep, and cased with four-inch pipe to a depth of 565 feet. There has been considerable decrease in the flow here, from causes unknown.

The well at Riverside Cemetery is 370 feet deep, cased with five and five-eighths inch pipe. The flow here is extremely large, the head about fifty-five feet, and there has been no decrease since the completion of the well.

The well at the Electric Light Works is 375 feet deep, well cased, and the flow here has always been unvarying during the ten months since its completion. Unusual care was taken in making tight joints, and the casing was very carefully put down. The well is one of the most reliable in the city.

The well at the Grant Smelter is 621 feet deep, of which 387 feet are cased with seven and five-eighths inch pipe, and 555 feet with five and five-eighths inch pipe. The first flow was encountered at 130 feet, the second at 180, third at 240, the fourth, the first large flow, at 325 feet. Several others were cut above 575 feet, at which point the main flow was encountered. The outer casing is perforated in two places to admit upper flows. The well is packed at 100 feet with a seed bag, and upon this seed bag 300 pounds of cement have been set. At a depth of 300 feet another seed-bag was put, against

a seam of clay slate. When finished, the pressure from the upper flows was thirty-five pounds, and from the lower forty-five pounds.

The Villa Park well, in Barnum's sub-division, is 760 feet deep, and cased for fifty feet with nine inch pipe, 140 feet with six and five-eighths inch, and for 730 feet with five and three-sixteenths inch pipe. The first flow cut was at 650 feet, and was light; the main flow being reached at 750 feet. No packing was used. The water here had a taint of sulphur and iron in it.

The well of the Steam Heating Company is three hundred and thirty feet deep and cased for two hundred and eighty with five and five-eighth inch pipe. When first struck this well gave a pressure of forty pounds per square inch; but this decreased, and it is now said to be again increasing. At first the supply was estimated at 180,000 gallons daily. This well is packed at the bed rock, and also at or near the bottom of the casing.

The Lindell well at the Lindell Hotel is three hundred and sixty feet deep, and cased to the bottom with four inch pipe. The flow here has been perfectly constant, and no decrease has been noticed. The pressure and flow have not been estimated.

The county well at the Court House was originally to be sunk to a depth of 1,500 feet, but after reaching a depth of seven hundred feet the great difficulties encountered and the delays caused thereby induced the abandonment of the attempt to go below the nine hundred foot point where a fair sized body of water was struck, which differs essentially from the water of the upper flows, as the analyses indicate. The well is cased separately for the six hundred and nine hundred and ten foot flows. Below six hundred feet the bore showed nothing interesting, alternate layers of sands and clays following each other. The flow at the six hundred foot seam was in no way different in pressure or volume from that found at the same depth elsewhere.

The Gurley well in North Denver is five hundred and twenty-five feet deep, and cased the entire distance. The water-

bearing seam was struck at five hundred and ten feet, and the casing is perforated at this point to admit the flow. The flow is a good one and the pressure about forty-five pounds. It is packed with seed bags above the lowest sand, and no decrease in supply has been observed.

The Reeves well on Boulevard Highlands, North Denver, has recently been completed. It is five hundred and forty-one feet deep, and cased for five hundred feet with five and five-eighth and four inch pipe. The head is about fifty feet and the supply about fifteen gallons per minute. No packing was used, but the pipe is down firmly into the sand rock.

The Kinsey well at the corner of Eighteenth and California streets is six hundred and twenty-five feet deep, and is cased for six hundred feet with four inch pipe. The sand was struck at six hundred and fifteen feet, and the head furnished is about sixty feet, and the supply approximately sixty gallons per minute. Flows were struck at two hundred and eighty, five hundred and eighty and six hundred and fifteen feet. The well is thoroughly packed with shot, iron filings, beans, etc. The upper flows are cut off, and the lower flow only utilized.

The Daniels & Fisher well in the alley, in the rear of Daniels & Fisher's store, is five hundred and seventy-five feet deep of which five hundred feet is cased with nine inch pipe, and the remainder with six and five-eighths inch pipe. The two hundred and seventy-five foot flow here was not struck, and at three hundred and fifty a seam of water bearing sand was cut which, however did not furnish pressure sufficient to force the water quite to the surface.

The McClelland well in the alley behind the Tribune building, is 607 feet deep and cased for 542 feet, with five and three-eighths inch pipe. The flow is extremely large, being estimated at 180,000 gallons per day, and the head about sixty feet. The well is carefully bored and well cased and packed.

The Schindelholz well at Twenty-sixth and Holladay streets, is 416 feet deep, cased to the bottom with three inch pipe. One flow only was cut. The casing is cemented against a hard clay slate seam, ten feet above the water bearing sand,

with a seed-bag upon which cement has also been placed. The head here is forty feet.

The Neighborhood well on Twenty-ninth, between Champa and Stout streets, is 460 feet deep, and is cased with three inch pipe. Flows of water were encountered at 392 and 440 feet. The pressure here is thirty-two pounds, and there has been no decrease.

The Waverly well, at the corner of Waverly, at Twenty-third streets, is 860 feet deep, cased for 579 feet with four and a half inch pipe, and about 730 feet with three inch pipe. Flows were struck at 310, 580 and 730 feet. The upper flows are shut off, and the lowest flow only is used, this giving a head of fifty-two feet. No packing was used. The well supplies a neighborhood embracing some four blocks.

The Swift well, on Twenty-eighth street, between Champa and Stout, is 457 feet deep, and cased with three inch pipe for 345 feet. One flow of water cut at 345 feet. Pressure when first struck, thirty-two pounds. This flow has decreased since, until now the pressure is not more than eight pounds. The cause of the decrease is not known.

SOME GENERAL OBSERVATIONS.

Careful observations of all the principal wells in the Denver basin show that in some cases the flow from the wells has been uniform and unvarying; that the greater number show some decrease; and that in one or two cases the flow has practically ceased.

Those wells in which the pressure has not varied at all are mainly those sunk within the last few months, and in which greatly improved machinery was employed in the work. Others, sunk in 1883, in which no decrease has been noticed, were generally characterized by great care in the insertion of packing both near the surface and just above the flows utilized.

The variations in pressure which have been observed are due to two or three very obvious causes. Perhaps the principal cause of decrease of pressure in most of the cases noticed

has been due to the sinking of other wells in the immediate vicinity, the aggregate capacity of the wells exceeding the supplying power of the sandstones, the consequence being a lowering of the head in all of the wells adjacent. This fact is illustrated well by the variations in the Charles block well at the corner of Curtis and Fifteenth streets. This well was the first to cut the 600-foot seam, and for a time the pressure remained quite constant, ranging from sixty-eight to seventy-one pounds per square inch. The sinking of other wells to the same flow was marked by conspicuous decreases in this pressure until to-day the average may be put at about twenty pounds per square inch. When the Daniels & Fisher well reached the 600-foot flow the pressure in the Charles decreased to from ten to fifteen pounds, afterward recovering, until the completion of the McClelland well in the Tribune alley, when the flow from the Charles well ceased entirely for a little over a day, when it reappeared with a force of only about ten pounds until the connections on these two wells were made, when the pressure again increased to about an average force of twenty pounds to the square inch, although daily variations are noticed within a small limit. Mr. Charles also states that the pressure is greater during the night than during the day. Another conspicuous example of the effects of sinking new wells near others is shown in the experience of the Denver Water company, who sunk a well 555 feet, obtaining a flow of about ninety-five gallons per minute. A second well was sunk 250 feet away, and when the same seam of sand was reached the pressure in the first was diminished so that the flow was only about two-thirds of that obtained at first. A third well was then sunk at a point about 250 feet from each of the others, producing such a decrease in the other two that the combined flow from the three wells exceeded only very slightly the capacity of the first well alone. Another well sunk 1,500 feet away produced no apparent effect upon these three wells.

Another cause of a decrease of flow is imperfect casing, which allows a waste from the lower flows with greater pres-

sure into upper seams of sandstone the water from which did not rise to the surface, and to waste into the surface material just above the "hard pan" or bed rock, this surface material consisting mainly of gravel and sand intermingled with soil and affording an easy and ready passage to a large volume of water. The well at the Zang brewery in North Denver, is a case which well illustrates this fact. This well was the second one sunk in Denver, and the machinery and tools used were of the crudest form, and the work poorly done. Later Mr. Zang put down casing, but the leakage probably continued outside of this casing into the sands and wash above, and but little or no improvement in the pressure was noticed, only enough water being furnished to supply the boilers and a small local demand for domestic use. The well in the Opera House is another example of the same fact. This well is 390 feet deep, of which but 200 feet are cased. The consequence has been that there has been considerable caving, and the flow has decreased from thirty-two to two pounds per square inch. The engineer of the block asserts that the pressure and flow are again increasing.

Fruitful sources of loss are the absence of or defects in packing around the casing to prevent the escape of water outside of the casing into upper seams of sand rock, and imperfect and leaky joints in the pipe, permitting loss which steadily grows in volume. The great waste and carelessness which has characterized the treatment of wells, tending, as it does, to maintain a steady drain upon the supply also diminishes the head and capacity of established wells.

In the rare cases where the flow has almost entirely ceased, the cause may be attributed solely to defective work.

The greatest care in putting in good casing, and substantial packing with seed bags, cement, shot, iron filings, or anything else which is suitable, should always be exercised, as its neglect is generally the cause of a decrease, and to this neglect the expenses of reboring, casing and packing can always be attributed.

So far, experience has not shown that the supplying

capacity of the sands, either of the 375-foot or 600-foot seams has been reached by the aggregate flowing capacity of all the wells in the Denver basin; and it is known that below these two main water-bearing strata there are a series of others which will probably be reached in succession to a depth of at least 1,500 feet.

An interesting fact which may be noted is that since May 15th there has been some increase of pressure and flow in several wells, all of which are in the 375-foot seam. Among these wells in which the pressure has increased are the Opera House (pressure doubled), the Eckhart, Electric Light, and Steam Heating wells.

This increase is attributed popularly to the thaw at the source of the supply, and this supposition seems likely, but it is noteworthy that so far only the upper flow has been affected. The time in which this increase has been noticed is too short to admit of any positive statements.

The question of preventing waste is an exceedingly important one, and should be made the subject of new, special legislation. Most of the wells seem to rival each other in the quantity of waste possible, and if the original supply has limitations at all, it may possibly be exhausted simply by extravagance and ignorance. The benefits to be derived from this artesian water by the public at large in obtaining a pure and healthy water in place of water from the Platte, the saving of water rents to large companies, the advantages to machinery, together with a large complement of other reasons, render the abuse of this, God's gift, almost a crime. Though legal action under existing ordinances has not yet been taken in the matter of regulating the use and abuse of the artesian supply, it seems likely that necessity will soon compel it.

MACHINERY USED IN BORING.

The tools and machinery used in sinking artesian wells in the Denver basin are usually of a very simple description. A boiler of about twenty-horse power, and a reversible link-

motion steam engine of about fifteen-horse power, furnish power sufficient to sink to any depth necessary here.

The engine is directly connected with a "band-wheel," which oscillates the walking-beam. At the further end of the walking-beam is attached a short rope, terminating with a temper-screw. At the lower part of the temper-screw the sinking-cable is attached by means of an adjustable clamp. The drilling portion of the machinery weighs about 2,600 pounds, and consists first of a bit of the kind usually called a "club" bit, which is screwed into the lower end of the "augur-stem." This augur-stem is a rod of iron about thirty-two feet long and three and one-quarter inches in diameter, and upon its upper end are screwed the "jars" or links, and to them the "sinker-bar," which is usually a three and one-quarter-inch bar of round iron, about fourteen feet long. To its upper portion is attached by screwing a rope socket by which the whole is united with the cable. The bit is a solid mass of steel, and is dressed out at its lower or cutting end to a width of from five and one-half to ten inches, according to the diameter of the hole. The part played by the "jars" is very important. When the entire drilling apparatus is lifted, these jars are extended to their full length, but when the mass is lowered the drill meets the rock through which it is advancing, stops and is struck upon the top by the sinker-bar, which plays through the jars.

To enlarge the bore or smooth its sides before inserting casing, a "rimmer" of steel, weighing about 125 pounds, is attached to the lower part of the auger stem in place of the bit. The drilling rope is of manilla, from 1¼ to 1½ inches in diameter, and of a length necessary to complete the boring. This rope, after passing through the temper screw clamp, is attached to the "bull wheel," which is connected with the band wheel by a "bull rope." Above the well is a derrick of lumber, and usually about 64 feet high, which is used for lifting the tools and drill. The stroke of the walking beam is adjustable, and varies from about 15 inches, at the upper part of the work, to about 36 inches at the lower portion of the well. After

three or four feet are drilled, the drill is lifted out, and the "sand pump" lowered. This sand pump is a tube of light iron 12 feet long, and with a valve at its lower extremity. The sand pump is attached to a manilla rope ¾ of an inch in diameter, and is lifted by a friction pulley on the band wheel. Two shifts of two men each, a driller and a tool-dresser, are employed. Much skill is necessary in the driller, who regulates the play of the sinker bar upon the drill by means of the temper screw, and the success or failure of an attempt to sink depends largely upon the driller's practical knowledge and experience.

The principal difficulties arise from caving in of soft strata above and from loss of the tools or sections of casing. When great trouble is experienced from caving, the bore is cased to its lowest point and a drill of less width substituted. Where tools or casing are lost, very difficult problems arise, and the greatest judgment and very expensive tools are required to remedy the difficulty. Where casing is lost, a plug of iron or "casing spear" is generally "jarred" firmly into the lost joint, and the whole lifted out. Where tools are lost, the implements used for their recovery vary according to the circumstances.

Some very difficult feats have been performed in this work, sometimes a hole being drilled into a solid steel rimmer over a thousand feet down in the well, a thread cut, and into this thread a screw attached to the cable inserted and the whole lifted out. As elsewhere stated, the cost of sinking an artesian well in Denver is about $2.00 per foot.

SECTION III.—BY REGIS CHAUVENET.

Chemistry of the Wells.

The following are the analyses of some Denver artesian waters, viz: Anderson's well; Windsor well, upper flow; Windsor well, lower flow; Court House well, lower flow.

Samples of the three first were collected by a member of the committee and forwarded to Golden. The care with which the Court House water was collected cannot be vouched for, but it is assured that every care was taken to send a correct sample in a clean vessel. Its analysis is included in this report, as the difference between this and the first three waters named is great, not only in the amount of solid residue, but in the presence of chlorine in noticeable quantity. Attention is also called to the fact that in this water only was lime found in excess over sulphuric acid. The remarkable similarity between the first three waters is seen at a glance.

In tabulating the results the probable "rational" analyses, both in grains per gallon, [United States gallon of 231 cubic inches, or 58,320 grains,] and in parts in 100,000 is given first. Below are added the actual results, by separate constituents. Carbonic acid is not included, as it was impossible, after much delay to secure any suitable apparatus for gas determinations in Denver. The analyses are, then, simply records of amounts of solid residues, and the analyses of those residues.

Nearly every determination was made in duplicate; several in triplicate. Qualitative tests for the higher metals, as well as for sulphuretted hydrogen, iodine and bromine failed to give the faintest reactions. Upon concentration, faint acidulation and treatment with sulphuretted hydrogen, an almost im-

perceptible tint was developed, but it was not identified as metallic, nor could any characteristic reaction be obtained, and it is assumed to have been merely caused by separated sulphur mixed with the small but inevitable amount of inorganic dust which settles in every atmosphere.

The soda was determined as follows: A portion of the water being evaporated to dryness in platinum, the residue was taken up with sulphuric acid, and again evaporated. The residue was disolved in water, filtered from separated silica, and precipitated with barium acetate. The filtrate containing all the bases as acetates was evaporated to dryness in platinum, and ignited strongly. All the bases now remain as carbonates, and it remains only to boil with water to extract the sodium carbonate, and filter from the insoluble carbonates of barium, calcium and magnesium. This final filtrate, acidulated with hydrochloric acid is treated in the usual way.

Thanks are due to Mr. Chas. A. Gehrmann, one of the more advanced students in chemistry, in the School of Mines, for valuable assistance in the course of the investigation.

ANDERSON WELL.

	GRAINS TO GAL.	PARTS IN 100,000.
Solid residue	10.41	17.85
Calcium Sulphate	0.87	1.49
Sodium Carbonate	8.22	14.09
Sodium Sulphate	0.44	0.75
Magnesium Chloride	0.10	0.17
Ferrous Carbonate	0.03	0.05
Silica	0.69	1.18
	10.35	17.73
Lime (CaO)	0.36	0.62
Magnesia (MgO)	0.04	0.07
Soda (Na_2O)	5.00	8.57
Ferrous Oxide (FeO)	0.02	0.03
Sulphuric Oxide (SO_3)	0.76	1.30
Silica (SiO_2)	0.69	1.18
Chlorine (Cl)	0.07	0.12

WINDSOR WELL—UPPER FLOW.

	GRAINS TO GALLON.	PARTS IN 100,000.
Solid residue	10.03	17.20
Calcium Sulphate	0.85	1.46
Sodium Carbonate	7.93	13.60
Sodium Sulphate	0.44	0.75
Magnesium Chloride	0.10	0.17
Ferrous Carbonate	0.03	0.05
Silica	0.61	1.05
	9.96	17.08
Lime (CaO)	0.35	0.60
Magnesia (MgO)	0.04	0.07
Soda (Na_2O)	4.83	8.28
Ferrous Oxide (FeO)	0.02	0.03
Sulphuric Oxide (SO_3)	0.76	1.30
Silica (SiO_2)	0.61	1.05
Chlorine (Cl)	0.07	0.12

WINDSOR WELL—LOWER FLOW.

	GRAINS TO GAL.	PARTS IN 100,000.
Solid residue	10.76	18.45
Calcium sulphate	0.92	1.58
Sodium carbonate	8.48	14.54
Sodium sulphate	0.44	0.75
Magnesium chloride	0.07	0.12
Ferrous carbonate	0.03	0.05
Silica	0.76	1.30
	10.70	18.34
Lime (Ca O)	0.38	0.65
Magnesia (Mg O)	0.03	0.05
Soda (Na_2 O)	5.15	8.83
Ferrous oxide (Fe O)	0.02	0.03
Sulphuric oxide (SO_3)	0.79	1.35
Silica (SiO_2)	0.76	1.30
Chlorine (Cl)	0.05	0.08

COURT HOUSE WELL.

	GRAINS TO GAL.	PARTS IN 100,000.
Solid residue	33.01	56.60
Calcium Sulphate	0.36	0.62
Calcium Carbonate	1.64	2.81
Sodium Carbonate	15.83	27.14
Sodium Chloride	14.04	24.07
Magnesium Carbonate	0.32	0.55
Ferrous Carbonate	0.06	0.10
Silica	0.63	1.08
	32.88	56.37
Lime (CaO)	1.07	1.84
Magnesia (MgO)	0.15	0.26
Soda (Na_2O)	16.71	28.65
Ferrous Oxide (FeO)	0.04	0.07
Sulphuric Oxide (SO_3)	0.21	0.36
Silica (SiO_2)	0.63	1.08
Chlorine (Cl)	8.52	14.61

SECTION IV.—BY P. H. VAN DIEST.

General Information.

A small proportion of the area of any district consists of river courses, even if the channels of the gulches are included, but the rain falls alike on the whole surface. Evaporation removes a great deal, but an important part reaches the underlying rocks. Some of these are sandstones, allowing water to enter them easily, others are clays, shutting off the passage of water, even preventing water accumulated in a permeable bed from rising.

Water reaching a permeable bed will at once be absorbed into the substance of the bed, besides traversing all open passages, minute or large. Water reaching the impermeable beds will remain on their surface or run down into cracks and fissures in the rock.

The quantity of water capable of being held by ordinary sandstones is about a gallon to every cubic foot. A better appreciation of this quantity can be obtained by assuming beneath the surface at any depth, between impermeable beds, exists a space ten miles square of sandstone thirty feet thick. We can calculate that this sandstone would be capable of containing between forty and fifty thousand millions of gallons of water and if these sandstone beds were fed from above by the rainfall of a district, of say a hundred square miles, on which the rainfall was fourteen and one-half inches per annum, (which is the average here,) of which one-third part enters the earth, it would need six years to accumulate the quantity named.

It is evident that the underground store of water must generally be greatly in excess of the mean annual supply, and

although really dependent upon the rainfall ultimately, is rather dependent upon the average than upon any particular season. This can be admitted as a rule for extensive layers at considerable depth fed by a drainage area of fair extent. Shallow permeable layers of small extent, fed by local seepage will, of course, be more dependent on the seasons, and the flow of wells sunk into such a permeable bed will be soon affected by a continuous dry season or a severe frost.

Of the rain that falls upon the earth at any place during a given period it is calculated that not more than one-third runs off the surface and enters the sea by rivers. This calculation cannot be very exact, and must vary greatly at different seasons and in different climates, but it may be taken as the best known approximation. Of the rest, part is evaporated, part of it feeds animal and vegetable life, but an ample supply remains to enter the earth.

The Seine, near Paris, carries off 160,000,000,000 gallons of water; the rain surface of the Seine district is about 3,000,000 acres, on which the yearly rainfall is nineteen inches, giving 460,000,000,000 gallons. A third thus of the whole rainfall forms the visible water stream. Of the remaining two-thirds, twenty per cent. evaporates; forty-five per cent. is consumed by vegetation, of which the leaves evaporate a part, and thirty-five per cent. enters into the earth, or twenty-three per cent. of the whole amount of rain.

Most soils absorb water and allow it to sink down to the subsoil. Beneath the subsoil is the rock; into this the water penetrates either by absorption or by the innumerable crevices and larger fissures that break it up into fragments. The water may run for quite a distance over an impermeable layer below the subsoil, but finally it meets with a permeable rock, and through this it runs, now through a large mass, slowly and with much friction, and now into open cavities or through channels conveying it horizontally or even bringing it up again under the influence of the pressure of a column the height of which has reference to the level of the spot at which it first entered as rain.

As the greater part of the rain falls on the mountains and high grounds and the rocks are generally tilted towards the plains, the tendency of water to run down a slope, which is the case in the interior of the earth as on its surface, ensures the conveyance of ample supplies.

As the dip of the strata is not always the same as the natural slope of the surface, it will happen that the water entering the strata above will issue at some lower level at a distance and well up at a fault, or at some artificial cutting, and reach the surface again, but always at a lower level than that at which it entered.

The study of a map of the surroundings of Denver shows that the city lies about in the centre of the curve of a horse shoe basin. The curve extends from Golden southerly to a mile and a half east of Morrison, thence south and south-easterly to a point about four miles south of Archers, thence northerly along the High Line ditch to a point two miles east of Platte Junction, thence east, north-east, crossing Coal Creek towards the Box Elder. This line connects points 5,650 feet above the sea level and 400 feet above the centre of Denver.

On the west and south-west and at some spots on the east, this line coincides with a line of the coal outcrop, the lowest strata of the Laramie. Layers cropping along this line may reach, as is mentioned in another part of this report, 1,500 feet below Denver.

Rain, falling outside this limit upon permeable sand and limestone outcroppings will be carried to a greater depth and may find ultimately natural outlets at points of lower altitude than Denver, a circumstance which would affect and diminish considerably the pressure when such strata were reached by boring at Denver. Besides it must be expected that below the coal at least 1,500 feet of clays must be bored through, as was demonstrated by the well at Greeley. Thus in all about 3,000 feet, before water layers of any account can be expected, fed by rainfall outside of the above indicated curve. Water entering the soil a few miles north of Denver will not contribute

much to the artesian supply of the city. Such water will be compelled to flow with the dip in a northerly direction towards natural outlets lower than Denver.

The above mentioned horseshoe curve, closed by an east and west line a few miles north of Denver, will thus limit the basin which can be considered as available for accumulation of of artesian supply for Denver. This basin has an area of 12,125,232,200 square feet.

The rainfall on this area is fourteen and one-half inches per year. It is difficult without elaborate observations and tests to determine how much of this enters the earth. In the Paris basin it is, as already mentioned, twenty-three per cent. Here the evaporation is no doubt a greater factor than in Paris, but on the other hand the vegetation will hére consume less.

To admit that twenty per cent. enters the earth here will not differ much from the truth; this is one-fifth of the fourteen and one-half inches, equal to twenty-four hundreths of a foot. This gives 2,922,180,000 cubic feet of water, or 21,916,-350,000 gallons per year.

But rainfall is not the only source of water within this basin. The many irrigation ditches bring a great amount of stored up water from rainfall outside of the basin within its limits. It is estimated that of the amount of water brought in at the upper part of the High Line ditch, not more than sixty per cent. is utilized for irrigation. This ditch has a capacity of nearly 300 cubic feet per second during the thirty maximum days; of one-third of that capacity during the thirty days before the 10th of June, and of a half during the thirty days of irrigation after the 10th of July.

The Table Mountain ditch has a capacity of 131½ cubic feet per second during the maximum season, and the Rocky Mountain ditch of 189 cubic feet, and the same ratio before and after the maximum discharge as given for the High Line ditch. The capacity of each, the two principal ditches heading in Bear Creek, not exactly known, will be very nearly equal to the capacity of the Table Mountain ditch.

The amount of water thus brought from outside the basin

within its limits is according to the above date not less than 31,104,000,000 gallons.

A good deal of this runs away in visible streams, as is amply demonstrated by the many gullies, ravines and arroyas, which were before known as dry and now are little rivulets, also by the many springs that were formed in the neighborhood of ditches, some feeding lakes and increasing their extent. Another and large part of the above named amount of water brought on by ditches is evaporated and consumed by vegetation, so that not more than was estimated of the rainfall, that is, twenty per cent., percolates to the subsoil. This twenty per cent. would make an additional supply of 6,220,800,000 gallons. The subsoil within the described basin absorbs thus yearly from different sources 28,137,150,000 gallons of water, or per diem 77,088,000 gallons. If this water supply was held in a basin compressed on every side, almost all of it could be brought to the surface within a small space by artesian wells.

Such a basin is, for instance, that in the valley of San Barnardino, California. The number of wells bored in San Barnardino and Los Angelos counties of an average depth of two hundred feet exceeds 1,000. Some of these wells irrigate one hundred to two hundred acres each.

The Paris basin can also be considered as enclosed on all sides and the out-croppings of permeable strata have in all directions a slight dip toward the centre, but such is not the case with the Denver basin. In the first place, the sandstone layers cropping out near Golden are tilted up at a very sharp angle, thus exposing a minimum surface to the percolating waters. In the second place, a good deal of the water reaching the subsoil within the extent of the described basin will follow the dip of the bedrock and of the underlying permeable layers toward the North, and thus flow away from Denver. This dip to the North can be estimated by the fact that the well of W. Meyers, twelve miles north of Denver, near the Pacific Railroad track, fully one hundred feet lower in altitude than Denver, reached the upper flow at the same depth, three

hundred and fifteen feet from the surface, that wells in Denver reached the same water bearing stratum. More northerly, above Platteville, the Platte increases in volume without visible side-flows, and at and above Platteville large bodies of underground water are reached at a depth of twenty to forty feet.

A considerable part of the calculated supply is thus lost for the artesian wells in and around Denver. This amount would be very large if the friction the water must encounter on its long journey to lower points was not very great in sandstones.

Limestones were not mentioned in this report as permeable strata, because they do not occur within the extent of the Denver basin. They are inferior to sandstones as an absorbent, but on the other hand, more available as a water-bearing rock, as being far more cracked and fissured, the water circulates more freely through them and with less friction. The greater friction in sandstones, although impeding the free flow and pressure, is here a favorable factor, because it prevents largely a great deal of water circulating in strata underlying Denver, from flowing away with the dip to the north, and it is kept and will rise to the surface when reached by a bore hole.

The observations made at Charleston, South Carolina, in regard to the result of artesian wells, illustrate the effect of friction very strikingly. A granite ridge about 110 miles from Charleston, crops out in favorable positions in Granite, Lexington, Columbia, Camden and Chesterfield counties, at a height of not less than 400 feet above sea level.

The Tertiary beds of the Charleston basin, the Cretaceous beds under them and other sedimentary beds beneath the Cretaceous rest againt the eastward slope of the granite ridge. Their sandy layers drink in the water filtering through the surface sands. As all these beds have a gentle slope toward the coast, the water will follow them down in their course.

The Coast Survey has shown that for some fifty miles from the shore off Charleston the bottom of the sea sinks gradually at about the same rate that the land has been descending. At a distance of fifty miles the sea reaches a depth of twenty

fathoms, then there is a more rapid increase to a depth of one hundred fathoms at about sixty-five miles, followed by an increase in eleven miles to more than 600 fathoms. The Eocene and Cretaceous formations encountered by wells therefore probably continue their course under water for over seventy-five miles, when they are cut off by the deep submarine valley which forms the bed of the Gulf Stream. There is evidence that the water contained in them finds a discharge into the sea. To this cause must be attributed the springs of fresh water that have been observed to rise through the salt water at points along the coast fifteen or twenty miles from the shore.

Thus the wells at Charleston tap the streams *in transitu*, and if there was not a great deal of friction encountered by the waters through the many miles of sand to the Gulf Stream outlet, the water would not rise in these wells to the surface. The water of several wells bored in Charleston to a depth of about 1,950 feet, rises four feet above the surface of the ground which is sixteen feet above mean low tide. The produce of these wells is, on an average, 250 gallons per minute.

It is not possible to estimate how much of the calculated amount of water percolating to the subsoil within the limits of the Denver basin is not available for artesian wells, on account of the described peculiar condition of that basin, but if so much as nine-tenths of the total is lost as the consequence of these conditions, still one-tenth or 7,708,800 gallons remains per diem, which can be discharged by artesian wells. This amount could supply a population of 150,000 with fifty gallons per capita daily.

HOW MUCH OF THAT UNDERGROUND DRAINAGE CAN BE BROUGHT TO THE SURFACE BY ARTESIAN WELLS?

If all wells were sunk to the available water strata, probably a depth of 1,500 feet, and by a series of casings all the flows were separated and brought to the surface and the tubes so well connected and sunk to the top and tightly closed upon each water stratum, not into it, so that nearly all leakage was prevented, then certainly nearly all of the above-named water

supply could be brought to the surface. But this cannot be expected. A good many wells are only run to a certain depth, giving a good flow, while upper flows are shut off and thus lost for use. Other wells are subject to great waste from bad casing, or the casing is not well set and part of the supply is lost in upper layers of less hydrostatic pressure.

The correct placing of the tubes is the most essential condition for success and one of the most delicate operations of the art of boring.

It is observed that the volume of water flowing from a well, increases with the diameter of the bore-hole. This increase is principally due to the diminution of the friction and resistance of the water ascending in the tube. On many grounds it would be advisable to bore wells of a larger diameter than that generally adopted in Denver. For deep bore-holes, principally for those exploring the sandstone strata between 800 and 1,500 feet deep, it is certainly most necessary, because the chances increase that a first casing cannot be pushed down to the full depth, and a new lining of smaller diameter must be resorted to.